Cloud research in the Hans-Ertel Centre Group

Shallow or deep, isolated or in groups, randomly distributed or organized, those are just many of the appearances cumulus clouds like to take in our summer skies. But why do clouds sometimes organize? Why do they deepen? Is a shallow cloud just lucky to deepen into a towering cumulus, or is there something more to it? Are external factors, e.g. the characteristics of the underlying land surface, important for the development and organization of such clouds? Do small-scale perturbations triggered by the presence of clouds actually matter for the future evolution of the atmospheric state on larger scales? And how could we better represent such phenomena in weather and climate models? The numerical mesh over which climate models represent atmospheric circulations is often too coarse to resolve clouds. This means that those clouds cannot be explicitly represented but their effects on the larger scales need to be represented in some statistical fashion, using a priori rules (parameterizations).

The Hans Ertel Centre (HErZ) research group in the department "The Atmosphere in the Earth System" at the Max Planck Institute for Meteorology (MPI-M) works with its group leaders Dr. Cathy Hohenegger (MPI-M) and Dr. Axel Seifert (DWD – German Meteorological Service) on these questions. The HErZ group is supported by MPI-M as well as by DWD. The Hans Ertel Centre as a whole, which entails five research groups spread throughout Germany, is an initiative by DWD [6].

Clouds, as condensed water vapour, thrive in a moist atmospheric column. As clouds also directly moisten the atmosphere through their mixing with the surrounding air, a positive feedback may emerge: shallow clouds gradually moisten the atmospheric column, which enables successive clouds to grow taller. This corresponds to the typical cloud development observed on a summer day, with shallow clouds in the morning and deep precipitating cumulonimbi in the evening. A detailed investigation of this cloud-cloud moistening feedback nevertheless has shown that this process, of clouds preconditioning their environment for their successors, is too slow to explain the observed cloud development [1]. The rapid deepening of the clouds has to be caused by circulations on scales larger than individual clouds, which both concentrate moisture on specific areas and force the air to ascend.

The formation mechanisms of such circulations are manifold and their effects on cloud development not negligible, as shown in different studies [4,5]. For example, mesoscale circulations triggered by surface heterogeneity can accelerate the transition to deep convection by almost a factor two.

Another important example is the organization of clouds, which is evident even for shallow clouds. Observations show that trade wind cumuli often organize in along-wind cloud streets and across-wind mesoscale arcs. So far numerical simulations have not been able to represent these patterns, often because they simply lacked the computational power to represent the scales of processes involved. Axel Seifert (DWD) and Thijs Heus (a postdoc in the HErZ group who is now at the University of Cologne) present large-eddy simulations (LES) that successfully reproduce all the important features of this cloud regime [3]. The self-organization into, e.g., the mesoscale arcs is traced back to cooling and moistening (cold pools) by precipitating shallow clouds; the cold air propagates in gust fronts and initiates the development of new clouds at the boundary. This organization also implies a clear growth in scale, from the small scale into the mesoscale. Both the organization, and the growth of scales poses a challenge for parameterizations.

How do the scientists investigate these clouds when current climate models are not able to resolve them? Detailed information on small-scale processes is obtained by conducting large-eddy simulations (LES, this means macro structure simulations, because only the largest turbulence eddies are resolved) on grid meshes whose spacing ranges from 10 to 100 m, and thus are capable of resolving cloud-scale circulations. LES are established in meteorology and engineering sciences as a method for numerical computation of turbulent eddy structures or flows. The HErZ group maintains a LES model developed at the University of California Los Angeles (UCLA) by Prof. Bjorn Stevens, head of the department "The Atmosphere in the Earth System". The model has been actively developed to incorporate ice microphysics, a land surface scheme, tracking features and Lagrangian particles. As such the full lifecycle of convection including the interactions with the heterogeneous land surface can be studied. Research on cloud scale processes complements work performed across the department at coarser resolution, e.g. in the climate modelling and climate dynamics group, and at even higher resolution in the turbulent mixing processes group, this also means that the same atmospheric phenomenon can be studied across the full spectrum of scales.

Using the results of such large-eddy simulations and in tight connection with DWD, the HErZ group has been developing new ideas and refining existing ideas to parameterize clouds; e.g. empirical double-Gaussian probability density functions have been formulated to parameterize cloud cover [2], or a stochastic scale aware shallow convection scheme is currently being developed. In such a model a population of subscale clouds is generated explicitly by a stochastic process, and these clouds can then interact with the larger-scale flow, i.e. the atmospheric model. The challenge here is to be able to include and correctly represent the organization of clouds as this fundamentally alters their lifecycle and their effects on atmospheric properties, and large-scale circulations, as a whole.

Further information:

http://www.mpimet.mpg.de/en/science/the-atmosphere-in-the-earth-system/working-groups/clouds-and-convection.html

http://www.dwd.de/bvbw/appmanager/bvbw/dwdwwwDesktop;jsessionid=vjzQTmhWnpnDxb8v4jFQ2JqJLmJjFTvvS4h8GN5TjktDL8KHvBSR!559158930!2132386675?_nfpb=true&_windowLabel=dwdwww_main_book&T17360039390127427067204gsbDocumentPath=Content%2FForschung%2FFEPK%2FErtel-Zentrum__teaser.html&switchLang=en&_pageLabel=_dwdwww_spezielle_nutzer_forschung

Publications:

[1] Hohenegger, C. and B. Stevens: Preconditioning deep convection with cumulus congestus. *J. Atmos. Sci., 70,* 448-464 **(2013)**.

[2] Naumann, A. K., A. Seifert, and J.-P. Mellado: A refined statistical cloud closure using double-Gaussian probability density functions. *Geo. Mod. Dev., 6,* 1641-1657 **(2013)**.

[3] Seifert, A and T. Heus: Large-eddy simulation of organized precipitating trade wind cumulus clouds. *Atmos. Chem. Pys., 13,* 5631-5645 **(2013)**.

Research

[4] Rieck M, C Hohenegger and C. C. van Heerwaarden: The influence of land surface heterogeneities on cloud size development. *In print for Mon. Wea. Rev.* **(2014)**.

[5] Schlemmer L and C Hohenegger: The frmation of wider and deeper clouds as a result of cold-pool dynamics. *In print for J. Atmos. Sci.* **(2014)**.

[6] Weissmann M., M. Göber, C. Hohenegger, T. Janjic, J. Keller, C. Ohlwein, A. Seifert, S. Trömel, T. Ulbrich, K. Wapler, C. Bollmezer and H. Deneke: Initial phase of the Hans-Ertel Centre for Weather Research - A virtual centre at the interface of basic and applied weather and climate research. *In print for Meteor. Z.* **(2014)**.

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